Building a model astrolabe

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This paper presents a hands-on introduction to the mediaeval astrolabe, based around a working model which can be constructed from photocopies of the supplied figures. As well as describing how to assemble the model, I also provide a brief explanation of how each of its various parts might be used. The printed version of this paper includes only the parts needed to build a single model prepared for use at latitudes around 52°N, but an accompanying electronic file archive includes equivalent images which can be used to build models prepared for use at any other latitude. The vector graphics scripts used to generate the models are also available for download, allowing customised astrolabes to be made.

Introduction

For nearly two thousand years, from the time of Hipparchus (*c.* 190–120 BCE) until the turn of the seventeenth century, the astrolabe was the most sophisticated astronomical instrument in widespread use. Yet today this complex instrument is rarely seen, and those interested in learning about it may even have some difficulty finding a specimen to play with. Ornately carved brass reproductions are available from several telescope dealers, but with substantial price tags attached. These price tags are historically authentic: mediaeval astrolabes were often made from high-cost materials and intricately decorated, becoming expensive items of beauty as well as practical observing instruments. But for the amateur astronomer who is looking for a toy with which to muse over past observing practice, a simpler alternative may be preferable.

In 1975–'6, Sigmund Eisner contributed a series of three papers[1,2,3] to this *Journal* entitled *Building Chaucer's Astrolabe*. In them, he described how a cardboard astrolabe might be built, using as a model the instrument described by the English poet Geoffrey Chaucer (*c.* 1343–1400) in his *Treatise on the Astrolabe* (1391).[4] Though the task described is a time-consuming exercise in geometry, it gives a rewarding insight, not only into how astrolabes were used, but also into their detailed construction and workings.

With the advent of computerised vector graphics, it has become possible to automate much of the delicate geometric construction work that Eisner describes. This paper describes the result of implementing a slightly modified version of Eisner's instructions in a computerised vector graphics scripting language called *PyXPlot*,[5] the interpreter for which is available for free download under the GNU General Public License (GPL).[6] The various parts of the resulting model are shown on subsequent pages; a later section will describe how they should be cut out and assembled. As an alternative to working with photocopies of the printed version of this paper, these figures are also available in computer printable PDF format from the electronic file archive which accompanies this paper; this can be downloaded from the BAA website at **http://britastro.org/astrolabe**.

As well as the figures printed here, which are prepared specifically for use at latitudes around 52°N, these archives also contain equivalent figures which may be used to build astrolabes prepared for use at other latitudes. In addition, they include the full PyXPlot scripts used to generate the model, which may be distributed freely under the GPL or modified to produce custom astrolabes. For more information, see **http://dcford.org.uk/astrolabe/astrolabe.pdf.**

The astrolabe

An astrolabe typically takes the form of a disc, often made of wood or brass, around 10–20 centimetres in diameter and a few millimetres thick. An eyelet protrudes from one side of the disc, through which a ring is connected as a handle. The body of this disc is called the *mother*, and one of its sides is designated as its front and the other as its back. Two freely rotating pointers are mounted on a central pivot, one on each side of the mother. The pointer on the back of the mother, known as the *alidade*, is used as a line along which to sight celestial or terrestrial objects when making approximate measurements of their altitudes. The front side of the instrument as a whole can be roughly described as a more sophisticated sibling of the modern planisphere, providing a way of predicting the altitudes and azimuths of celestial objects at any given time.

Beyond this rather loose description, astrolabes were historically built to many diverse designs. The emergence of the astrolabe as a single instrument began with the bringing together of two forerunners in Greece in the second century BC: the dioptra – an instrument for sighting the altitudes of celestial bodies – and planispheric projections which could be used to represent the celestial sphere on a flat surface. Together, they formed a single instrument which could simultaneously measure or predict the positions of celestial objects as required, becoming what might be described as an analogue celestial calculator. This powerful hybrid instrument spread to the Byzantine, Islamic and Persian worlds over subsequent

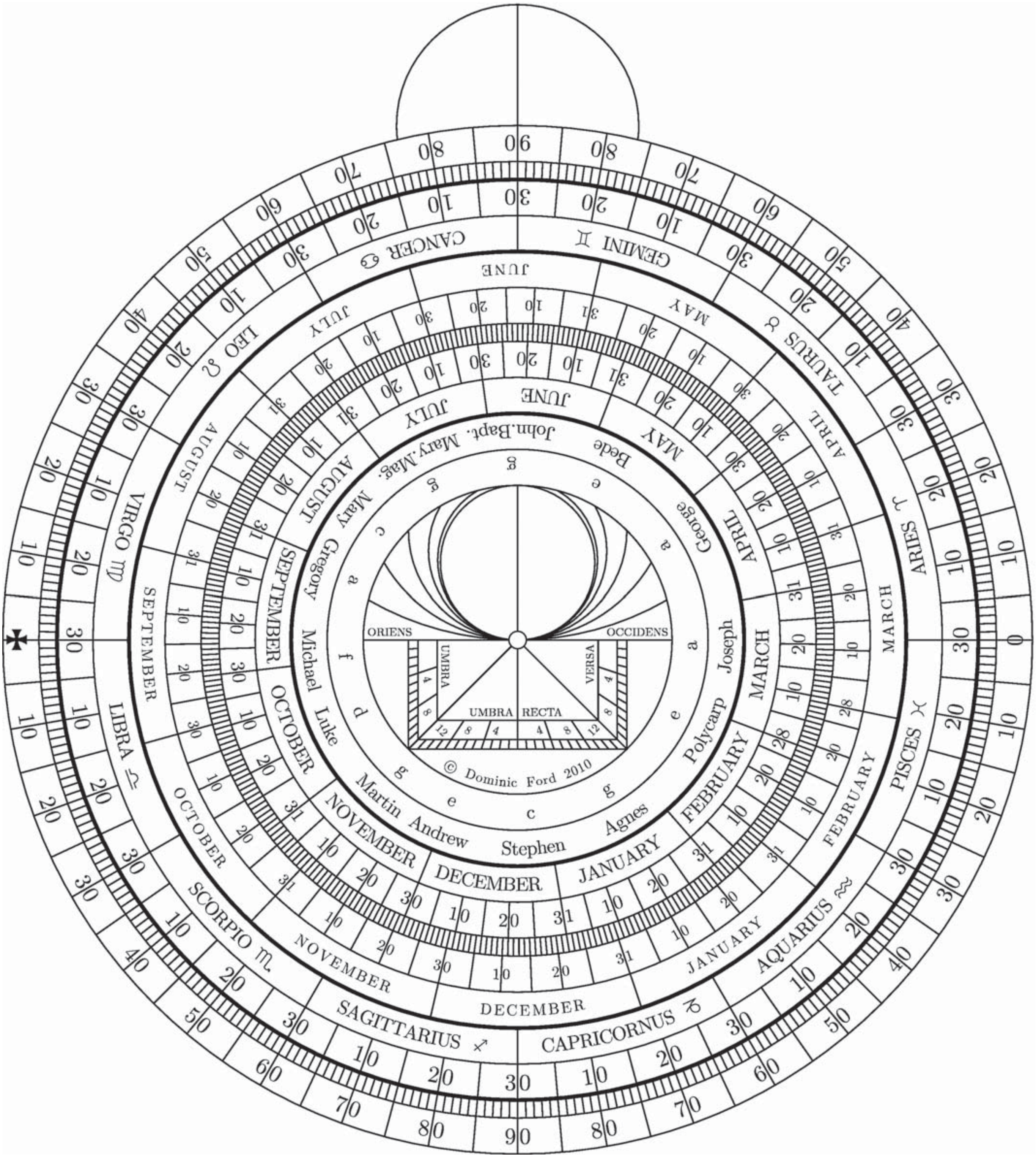

Figure 1. The back of the mother of the astrolabe.

centuries, evolving variously along the way. Some of the products of this evolution – for example, linear and spherical astrolabes – do not even fit within the deliberately loose description above, though they retain a common *raison d'être*. Another product, the mariner's astrolabe, emerged as a similar but distinct instrument, simplified and optimised for use on the deck of a rolling ship in the determination of latitude at sea. The subject of this paper is the astronomical astrolabe, which retained its same essential layout.

It is beyond the scope of this paper to discuss the historical development of the astrolabe any further, or to present a study of its historical use. The interested reader may find a fuller account of these subjects in John North's comprehensive history of astronomy, *Cosmos* (1998).[7] My aim in present-

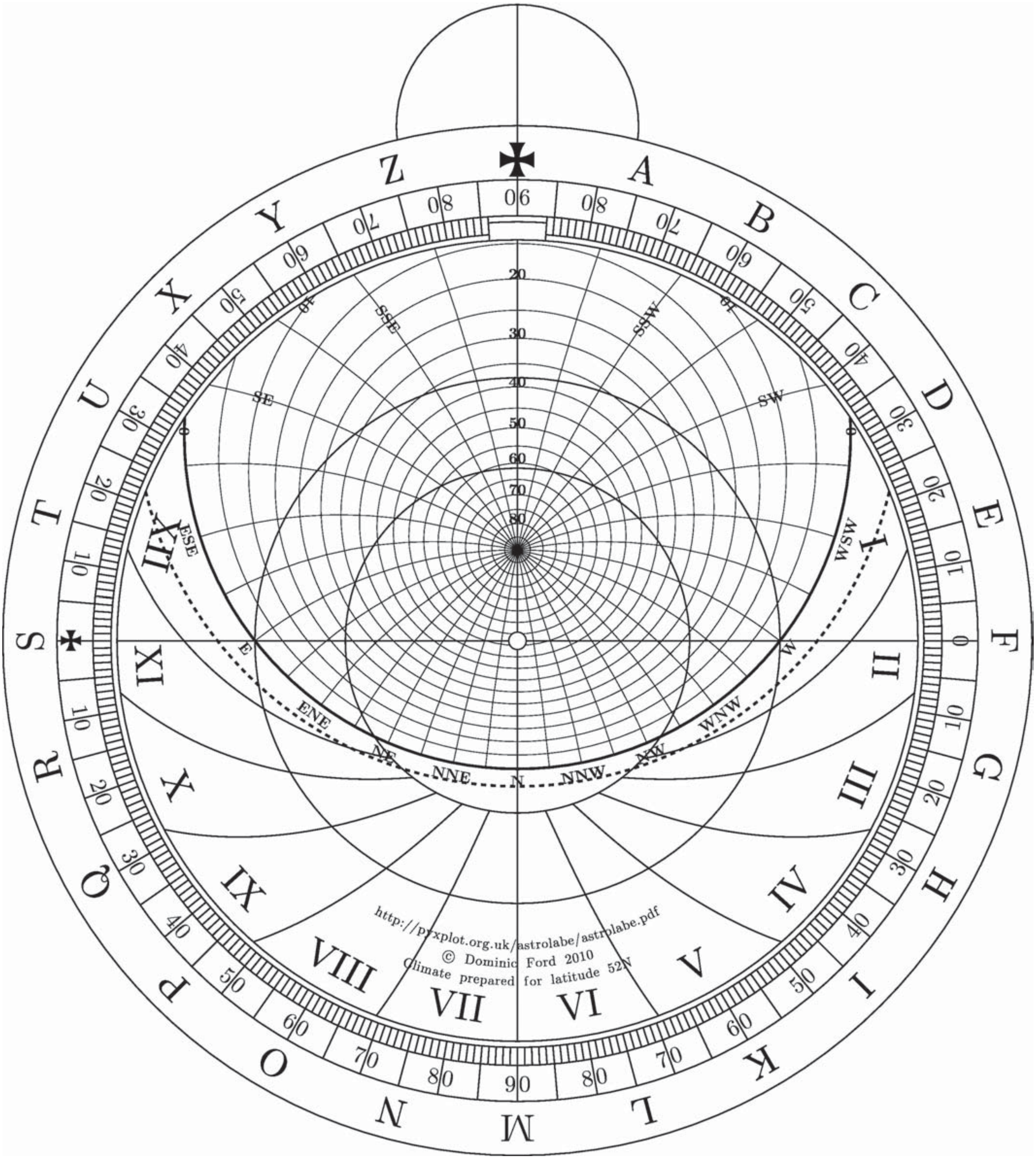

Figure 2. The front of the mother of the astrolabe, with combined climate prepared for a latitude of 52°N. Should a climate for a different latitude be required, the electronic file archive which accompanies this paper should be downloaded. This includes separate images of the front of the mother – the outer ring of the above image – and of climates for any latitude on the Earth at 2° intervals.

ing a single design of model astrolabe here is rather to provide a hands-on introduction to how a modern amateur astronomer might use such an instrument to make similar observations to those for which the astrolabe was historically used. The particular design of astrolabe which I present is loosely based upon one described in the 14th century by Chaucer, which dates from a time when astrolabes had recently arrived in Western Europe, and specifically Britain, through contact between Christian and Islamic scholars in Spain.

Since my aim is to convey the principles of the instrument rather than its precise historical appearance, two parts of the astrolabe have been slightly modernised to make them more immediately usable today. The calendar appearing on the astrolabe described by Chaucer has been updated from the Julian

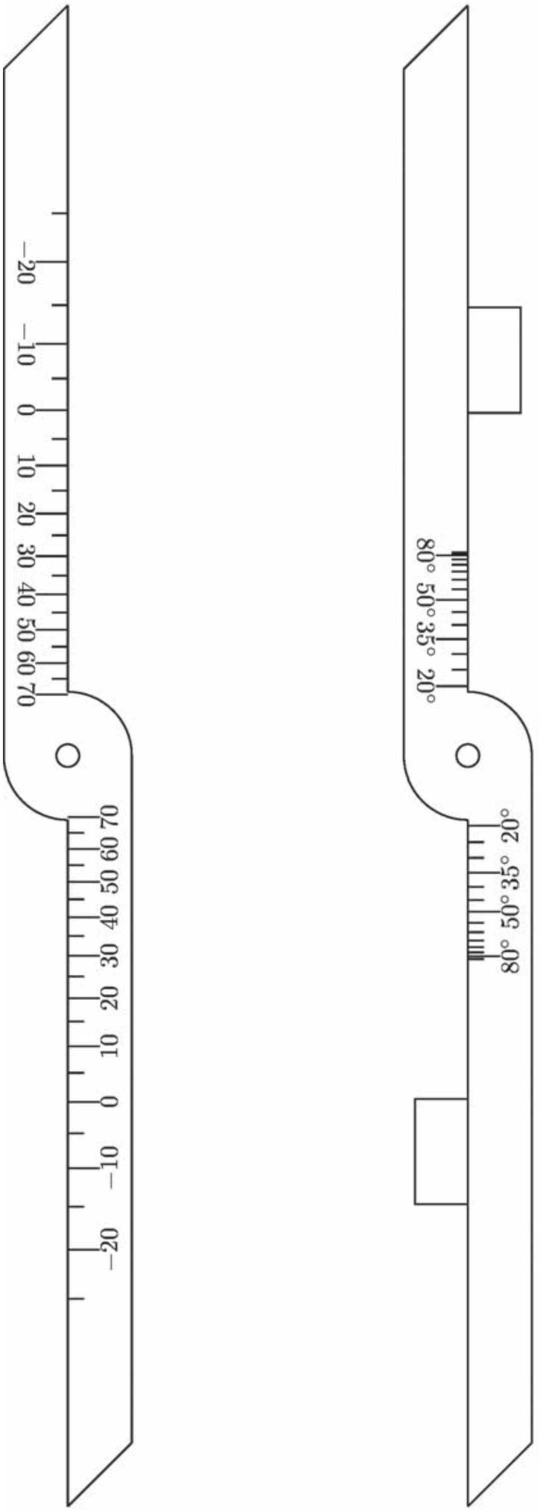

Figure 3. *Left:* The rule, which should be mounted on the front of the astrolabe. *Right:* The alidade, which should be mounted on the back of the astrolabe.

calendar to the Gregorian calendar, though the original is retained alongside its modern counterpart. More significantly, the star chart, known as the rete, has been transferred from brass latticework to transparent plastic, as will be described later. These changes notwithstanding, the principles of the observations and calculations which I describe are similar to and largely based upon those described by Chaucer and other historical sources, though mediaeval users would often have had astrological cosmologies in mind which are foreign to modern astronomers and are not described here.

Constructing a model astrolabe

To assemble the model astrolabe presented in this paper, Figures 1, 2 and 3 should be photocopied onto paper, or preferably onto thin card. Figure 4 should be photocopied onto a sheet of transparent plastic; acetate sheets, widely sold for printing overhead projector slides, are ideal for this. Alternatively, all of the figures in this paper may be obtained in PDF format from the accompanying electronic file archive. Some parts of the astrolabe are drawn with a particular latitude in mind and space permits only a single astrolabe designed for use at a latitude of 52°N to be included here. However, the PDF versions of these figures are accompanied by alternatives which can be used to make model astrolabes for use at any latitude between 84°N and 84°S, spaced at 2° intervals.

Once the components of the astrolabe have been printed and cut out, Figures 1 and 2 – the back and front of the mother – should be glued rigidly back-to-back, perhaps sandwiching a piece of rigid card. Figure 4 – the rete – should then be placed over the front of the mother. From Figure 3, the rule, on the left, should be placed over the rete on the front of the astrolabe, and the alidade, on the right, should be placed over the back of the astrolabe. The two rectangular tabs on the alidade should be folded out to form a sight for measuring the altitudes of objects. The holes at the centres of each of the components should be cut out, and a split-pin paper fastener used to fasten the components together, whilst still leaving them free to rotate. A second hole should be cut into the eyelet protruding from the top of the mother, allowing the whole instrument to be suspended from a ring or piece of thread.

The following sections describe in turn how each part of this model astrolabe may be used.

The back of the mother

Figure 1 shows the features marked on the back of the mother of the astrolabe. Over the top of this, the alidade, on the right side of Figure 3, is allowed to freely rotate about a central pivot, acting as a measuring ruler. Two tabs fold out of the edges of the alidade to act as a sight. To measure the altitude of a star, the astrolabe is suspended freely at eye level, traditionally from a ring hooked over the user's right thumb, and the alidade is rotated until both tabs appear in line with the star. The outermost scale on the astrolabe then indicates the star's altitude.

The remaining circles on the back of the mother are a calendar, referenced relative to the Sun's annual motion

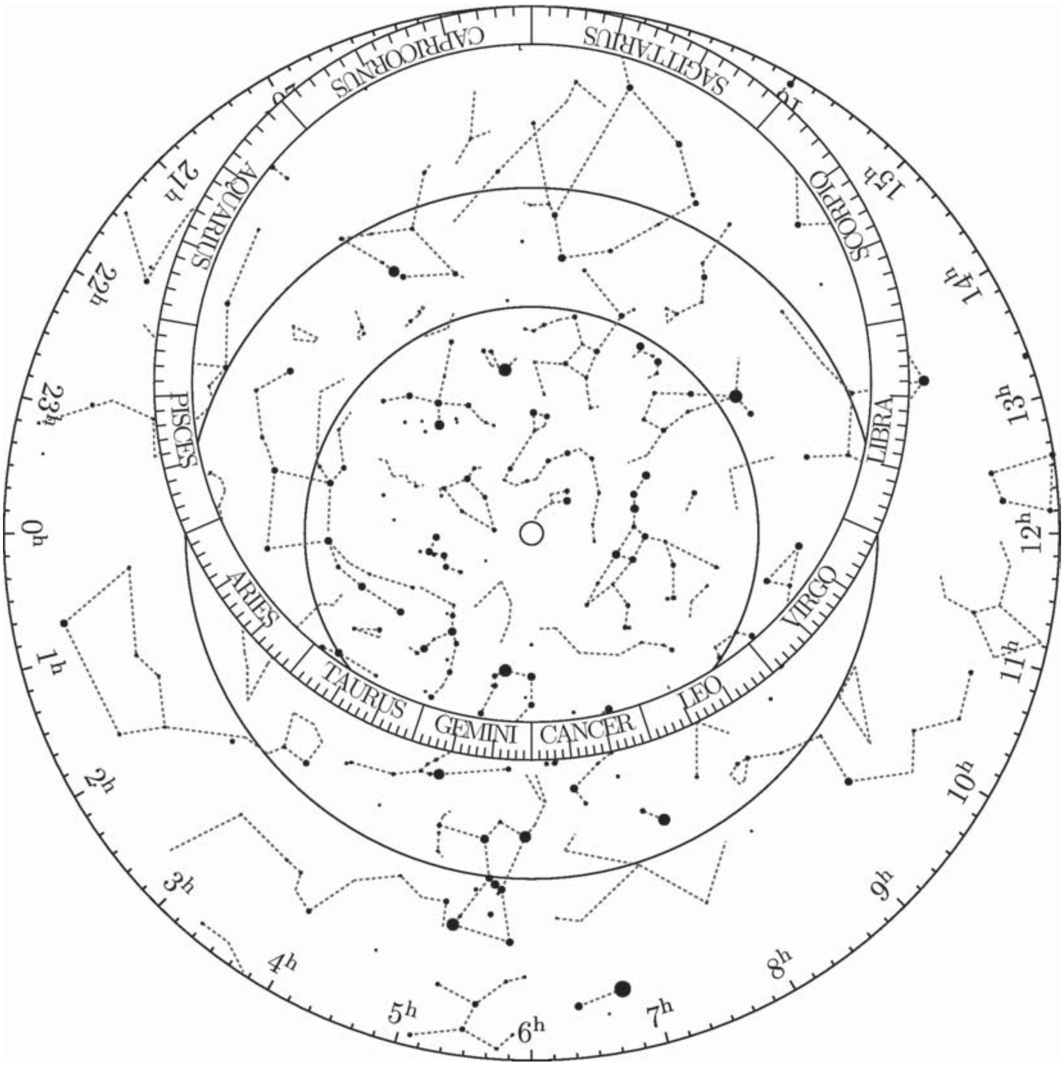

Figure 4. The rete of the astrolabe, showing the stars of the northern sky. This should be printed onto a piece of transparent paper; most stationers should be able to provide acetate sheets for use on overhead projectors, which are ideal for this purpose. Should a southern-hemisphere astrolabe be required, the electronic file archive which accompanies this paper should be downloaded.

along the ecliptic, such that each degree of the circular scale represents the time taken for the Sun to move one degree across the celestial sphere. The ecliptic circle is divided into twelve equal 30° portions, and each portion designated as a zodiacal constellation. The first of these, Aries, is defined to start at the vernal equinox, the point on the sky where the Sun's path crosses the equator in March. It should be noted that these ancient zodiacal constellations bear little relation to the 88 modern constellations known to astronomers today; the latter are a much newer creation which were only finalised by the International Astronomical Union (IAU) as a definitive list in 1922 and given rigid boundaries in 1930.

A scale divides the year into twelve parts as the Sun passes through each of these zodiacal constellations, and within this, a calendar provides a conversion to the familiar system of days and months. Together, these scales can be used for determining the celestial position of the Sun on any given date, which, as we shall see, needs to be known when the front side of the astrolabe is used. Following Eisner, two calendars are shown. The outer calendar, in small typeface, is computed for 1394, around the time of Chaucer's composition, using solar longitude data published by Tuckerman (1962, 1964).[8,9] This calendar should be used when following the example calculations described by Chaucer. The inner calendar is computed for 1974 – taken as the present day – using corresponding data published by Stahlman & Gingerich (1963),[10] and should be used for modern calculations.

These two calendars are offset by nine days relative to each other, which can be explained by the calendrical reforms which took place between 1394 and 1974. In 1394, the Julian calendar had been in use in Britain since Roman times. However, because it gave the year an average length of 365.25 days, some 11 minutes longer than its true length, the date of the vernal equinox drifted by around a day every 128 years. Though the vernal equinox had occurred around March 21 at the time of the Council of Nicaea in 325, by 1394 it was falling on March 12. This was a serious problem for the Catholic Church, which used the date of the equinox in calculating the date of Easter: should the traditional Nicene date be used, or that when the equinox was actually observed?

Primarily to resolve this confusion, Pope Gregory XIII reformed the calendar according to a plan approved by the Council of Trent (1545–1563), removing centurial leap years such that the average length of the year became 365.2425 days. In addition, the vernal equinox was restored to its traditional Nicene date by fast-forwarding the calendar by 10 days in 1582, though in Anglican Britain the new calendar was not adopted until 1752, by which time a shift of 11 days had become necessary. In contrast to the Julian calendar, the drift of the Gregorian calendar relative to the seasons is so slight – 10–20 seconds per year – that the seasons slip by only one day every few thousand years, so the calendar presented by Eisner for 1974 remains accurate for modern use.

The exact choice of the years 1394 and 1974, in each case midway between leap years, is deliberate. The exact moment of the vernal equinox drifts by a quarter of a day per year, but shifts back to its original position in the fourth year. These midpoint years consequently represent an average over the four-year cycle. In practice, however, this is a detail beyond the accuracy with which any real measurement can be made with an astrolabe.

In the centre of the back of the mother, a scale shows the dates of a number of significant saints' days, together with their Sunday letters, acting as waymarkers through the liturgical year. The choice of saints included here would vary widely, especially since space only permits the inclusion of one date every three weeks and local custom would often dictate those included. The saints included in Figure 1 were kindly selected by Matthew Smith and may reflect the bias of a contemporary Anglican. The innermost markings lying within the circle of saints will be described later.

The front of the mother

The front of the mother of the astrolabe is shown in Figure 2; the planispheric starchart in Figure 3 rotates over the top of the middle portion of Figure 2. This side of the astrolabe is similar to a modern planisphere, though it is arranged differently and can usually be adjusted to work at several latitudes, whereas modern planispheres are typically only designed for one particular latitude.

Around the edge of the mother twenty-four symbols are inscribed, beginning with a cross and then proceeding through the Roman alphabet. These represent the twenty-four hours of the day, with the cross representing noon and the letter 'M' midnight. Historically, these characters would have appeared, with the scale of degrees next to them, on a raised rim around the edge of the mother, encircling a large well in the middle which Chaucer calls the *womb* of the astrolabe. The circular *climate* (sometimes called the *plate* elsewhere) which appears in the centre of Figure 2 would have been a separate sheet of wood or brass which slotted into the womb. A tab at the top ensures that the climate is correctly aligned.

The reason for this design is that the positions of the lines drawn on the climate are latitude dependent, and an astrolabe would typically come with a supply of different climates for use at different latitudes. Usually the womb was deep enough that all of the climates could be stacked within for convenient storage. In Figure 2, for simplicity, only a single climate is provided for latitude 52°N and it is incorporated into the image of the front of the mother. In the accompanying PDF images, the traditional separation of mother and climate is observed.

On the rete appears a planispheric projection of the brightest stars in the northern sky; I have used the Yale Bright Star Catalogue[11] to mark all stars brighter than fourth magnitude. The projection used here is the same as is used on modern planispheres: if a star has right ascension α and declination δ, then it is plotted at a distance proportional to $\tan((90°+\delta)/2)$ from the centre and at azimuth α. Thus, the north pole appears at the centre. Three concentric circles are drawn around this to represent the Tropic of Cancer, the equator, and the Tropic of Capricorn, which is chosen as the outer edge of the astrolabe. It is not possible to continue the projection all the way to the south celestial pole, as this would appear at infinite distance from the centre. The pointer which rotates over the top of the rete, called the *rule* (sometimes the *label* elsewhere), is marked with this mapping between radius and declination, and can be used to read off the declinations of objects.

Traditionally, the rete would have been made from wood or brass, and arrows would have pointed to the positions of a small number of stars. Then, as much of the material of the rete as possible would have been cut out so that the climate beneath could be seen. Had transparent plastic been available in the Middle Ages, it would doubtless have been used, and would have allowed many more stars to be represented. Since the purpose here is not to reproduce a particular historical astrolabe, but rather to provide a working specimen that might be used by amateur astronomers today, this is the one component of the instrument where I have taken the liberty of substantial modernisation. It should also be noted that the scale of right ascension shown around the edge of Figure 4 would not have been present on historical instruments, but is provided as a navigational aid for the modern astronomer.

The annual path of the Sun across the celestial sphere is marked on the rete by the outer edge of a circular band on which the positions of the zodiacal constellations are marked out. As before, each represents an equal 30° portion of the ecliptic, though in the planispheric projection the northern constellations appear artificially shrunken compared to those in the south. To find the position of the Sun on any given day, the scale on the back of the mother is used. For example, on 1st June, the back of the mother tells us that the Sun has moved approximately 10° through the constellation of Gemini. Thus, on the rete, we see that the Sun is just a little to the north of Aldebaran.

The climate sits directly behind the rete and shows the horizon of the visible sky. Just as on a modern planisphere, the diurnal passage of the stars is reproduced by rotating the projection, and so as the rete is rotated clockwise, stars are seen to rise in the east and set in the west. The cobweb-like grid that criss-crosses the visible sky shows lines of constant altitude – called *almucantars* – and lines of constant azimuth – called *azimuths* – for determining the approximate alt/az coordinates of stars. Just beneath the hori-

zon, a dotted line marks the path six degrees beneath the horizon and may be used to calculate the times of civil twilight, defined to be when the Sun is between zero and six degrees below the horizon.

As is the case with a planisphere, the projection must be brought into the correct rotation to represent a particular time and date before it can be used. On a planisphere, this is usually done by matching the desired time on a rotating scale to the desired date on a static scale. On an astrolabe, however, no such scales are provided. Alignment is typically achieved by measuring the altitude of a reference object – either the Sun or a star – using the alidade and then rotating the rete until its projection lies on the appropriate almucantar; it is also necessary to have some sense of east and west in order to know whether to align the object so that it is rising or setting. This means that, in contrast to the planisphere, the time of day does not need to be accurately known *a priori* to align an astrolabe. The astrolabe can even be used to determine the time from altitude measurements.

As Chaucer observes, it is best when aligning the rete to select a reference object which is well away from the meridian. When an object transits, its altitude is momentarily unchanging, and even the slightest uncertainty in its altitude leads to a large uncertainty in the time. By contrast, when an object is in the east or the west, its altitude is changing most rapidly and there is no such difficulty.

The unequal hours

Before the advent of reliable mechanical clocks, it was common to divide each day not into twenty-four equal hours, but into twelve equal hours of daytime and twelve equal hours of nighttime. In winter, each hour of nighttime would be considerably longer than each corresponding hour of daytime, and in summer the converse would be true. These hours are hence known as *unequal hours*. The next section describes how to align the astrolabe using the equal hours with which we are now familiar, but I first describe how to use the system of unequal hours which would have been in widespread use in the Middle Ages.

The area of the climate beneath the horizon is divided into twelve curved strips. These relate to the fact that the circular path traversed by a star at any given radius from the centre of the rete – the radius representing its declination; see above – can generally be divided into a portion which lies above the horizon marked out on the climate, and a portion which lies beneath the horizon, unless the star is circumpolar. The portion of this circular path which lies beneath the horizon is divided into twelve equal parts by these curved strips.

To use these strips to tell the time, it is first necessary to determine the position of the Sun along the ecliptic using the scale on the back of the mother, as described previously. The position of the point diametrically opposite the Sun along the ecliptic – the antisolar point – should also be noted, by looking at the point on the opposite side of the back of the mother. Turning the astrolabe over, the rete should then be aligned, using a measurement of the altitude of either the Sun or a known star. Depending on whether it is day or night, either the antisolar point or the Sun respectively will be beneath the horizon; at sunset or sunrise, both will be on the horizon. At nighttime, the number of the strip in which the Sun lies is the hour of the night; the strips equally divide its path from the point where it sets on the western horizon to that where it rises on the eastern horizon. Conversely, in the day, the number of the strip in which the antisolar point lies is the hour of the day. At sunset and sunrise, the point used to determine the hour changes, and because the Sun and the antisolar point have opposite declinations, the astrolabe correctly produces daytime and nighttime hours of different lengths.

The calculation can also, of course, be done in reverse. To align the astrolabe to show what the sky would look like at any given hour of the day, the rete should be turned until the solar or antisolar point is in the correct place among the lines of the unequal hours.

The equal hours

The same alignments can also be made using the system of equal hours with which we are now more familiar, in which each day is divided into twenty-four hours of equal length. To do so, the sequence of twenty-four symbols around the edge of the mother is used, each of which signifies an hour of the day, with the cross marking noon and the letter ‘M’ midnight. The procedure is much simpler than that used to align to the unequal hours: the rule should be rotated to point to the desired hour around the outer scale, and the rete rotated beneath it until the Sun lies on the edge of the rule.

One detail is worthy of note here: the twenty-four symbols refer to the hours of local *apparent solar time*, defined such that noon occurs on any given day when the Sun is at its highest altitude in the sky. This may be found to be offset relative to civil time for two reasons. First, the observer will, in general, be some distance east or west of the meridian for which his civil timezone is defined. Secondly, the speed of the Sun’s motion in right ascension varies over the course of the year such that days in June and December are a few seconds longer than those in March and September. Civil time is a *mean time*, in which this variation is averaged over the course of the year, and as these seconds accumulate day-by-day, *apparent noon* can drift up to 16 minutes either side of midday depending upon the time of year. This offset is given by the equation of time.

The unequal hours: Method II

A second tool for calculating the time, in unequal hours, from the altitude of the Sun appears in the upper half of

the central portion of the back of the mother. This is a simple but imprecise tool, consisting of six partial arcs of circles all passing through the centre of the astrolabe. Before using these, it is necessary to know the maximum altitude at which the Sun will appear – at noon – on the day of observation. This can be determined using the front of the mother, once the location of the Sun along the ecliptic has been found. The answer varies little from one day to the next, and so only needs to be looked up rather infrequently. The scale of degrees marked along the alidade should then be studied to find the point on the scale corresponding to the maximum altitude of the Sun, which we shall call X.

The present altitude of the Sun should then be determined using the alidade. Keeping the alidade pointing to this altitude, the position of the point X among the six circular arcs should be determined. The smallest circle is drawn such that the point X always lies on it at noon. The point X crosses each of the other circles at hourly intervals, each circle being crossed twice each day, once as the Sun is rising, and once as it is setting. Thus, the gap between the zero-altitude line and the largest circle represents the first or the twelfth hour of the day, and the gap between the two smallest circles represents either the sixth or the seventh hour; it is necessary to determine whether the Sun is rising or setting to know which.

The shadow scale

Presented with the task of determining the distance to a building of known height h using an observation of the altitude Θ of its highest point, modern astronomers would probably turn to trigonometry. Reaching for their calculators, they would evaluate the tangent of Θ, which equals the ratio of the building's height to its distance. The distance to the building could be found by evaluating $h\times\tan\Theta$. Similarly, the height of a building of known distance d could be found by evaluating $d/\tan\Theta$.

The shadow scale, in the lower half of the central portion of the back of the mother, is an approximate analogue tool for making such calculations without the need for a separate lookup table of the tangent function, which is instead marked out on the astrolabe. The range of altitudes between 0° and 45° is divided into twelve parts, with lines denoting the points where $\tan\Theta$ is 1/12, 2/12, ..., 12/12. The line where $\tan\Theta = 4/12$, for example, is labeled '4'. The use of twelve as a denominator here is a good choice – much better than ten, for example – because of its having six factors: thus 3/12= 1/4, 4/12= 1/3, etc. Thus, when a building's highest point is at the altitude labeled '4', its height is four twelfths – or one third – of its distance. At an altitude of 45°, $\tan\Theta = 1 = 12/12$. Higher altitudes are similarly labelled with numbers between 1 and 12, denoting the points where $\tan\Theta = 12/12, 12/11, \ldots, 12/1$.

Remarks on extreme astrolabes

The accompanying electronic file archive includes images of astrolabes designed for use at any latitude between 84°N and 84°S, sampled at 2° intervals. However, the planispheric projection used in the star charts of these astrolabes works best at moderate-to-high latitudes. Since the sky is only mapped as far south as the Tropic of Capricorn, the southernmost portion of the sky is not shown for any latitude south of 66°N. Thus, whilst astrolabes are provided for all latitudes, those prepared for equatorial regions are missing large portions of the visible sky.

South of the equator, matters improve again if the projection is reversed and the celestial south pole placed at the centre of the rete. The notion of such a southern-hemisphere astrolabe would have been alien to Chaucer, but I nonetheless provide them for the curiosity of southern readers. In addition to the change of rete, one further reversal is required: whereas the retes of northern astrolabes rotate clockwise as time advances, this is reversed for southern retes. This is because while the Earth rotates clockwise as seen by an observer looking down on its north pole, it rotates anticlockwise as seen by an observer looking down on its south pole. In order that the sequence of Roman letters around the rim of the front of the mother should still represent twenty-four equal hours, their direction is reversed on southern astrolabes.

Within the Arctic and Antarctic circles, another problem is encountered: the system of unequal hours becomes ill-defined since the Sun never sets. In the climates provided for such latitudes, I have chosen a definition such that polar days and nights are divided into twelve equal hours between successive midnights. This definition interfaces smoothly with the days at the beginnings and ends of the polar days and nights where the Sun just rises or sets, and the unequal hours of the day or night are infinitesimally short.

Epilogue: The rise of precision astronomy

By the turn of the seventeenth century, the astrolabe was starting to be superseded. In 1576, Tycho Brahe laid the foundation stone of *Uraniborg*, a research institute on the small Danish island of Hven.[12,13] Over the following 21 years until its abandonment in 1597, this institute brought about a revolution in pre-telescopic astronomical instrumentation. Among the instruments pioneered under Tycho's direction were the sextant – which allowed the angular distances between stars to be precisely measured – and the mural quadrant – which allowed the altitudes of transiting stars to be measured with respect to a plumb line indicating the local vertical. At Uraniborg's observatory, *Stjerneborg*, these instruments achieved arcminute accuracy, close to the theoretical resolving power of the human eye.

Though Tycho guarded his intellectual property closely in his lifetime, knowledge of such instruments spread rapidly after his death in 1601, as his former assistants received appointments at observatories across Europe and Asia. As this was happening, Tycho's observations of planetary positions were being analysed by one of his theoretically-minded former assistants, Johannes Kepler, who found that the path followed by Mars could not be reproduced by either Ptolemaic planetary theory or Tycho's proposed replacement for it. Motivated by this, Kepler went on to develop his own planetary theory, showing that Tycho's data could be reproduced if the planets followed not circular, but elliptical orbits about the Sun. This conclusion vindicated Tycho's campaign of precise observation by demonstrating, as Tycho had hoped to do, that precise measurements of planetary positions could challenge ancient planetary theory, even though Kepler had at the same time disproved Tycho's own cosmological ideas.

Once the case for precision observation had been made, the astrolabe, a small handheld instrument, was no longer sufficient for astronomers' needs. By the mid-eighteenth century, the staple instrument for positional astronomy would be the transit instrument – an evolved form of Tycho's mural quadrant with a telescopic sight. Even outside observatories, the astrolabe was by now becoming largely redundant: as a chronometer, it could no longer compete with the clockwork rivals which were increasingly widely available and reliable.

Acknowledgments

The model presented in this paper came about initially at the suggestion of Katie Birkwood, Hoyle Project Associate at the Library, St John's College, Cambridge, who wanted a model astrolabe to use as the focus of an exhibition, *The Way to the Stars: Build Your Own Astrolabe*, during the Cambridge Science Festival in 2010 March. The model used in that exhibition, and still available from the associated website,[14] was a simplified version of that described here. I am grateful to Matthew Smith for compiling the list of saints' days shown in Figure 1, and to Michael Hoskin for his encouragement and for bringing John North's history of astronomy to my attention. Finally I would like to thank the referees of this paper, Mike Frost and Peter Meadows, for making several useful suggestions.

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